

FEASIBILITY SYUDY ON ENERGY RECOVERY SYSTEM IN 1 MW CW KLYSTRON FOR KOMAC

T. Y. Kim, K. C. Lee, S. J. Noh*, and K.H. Chung,

Dept. of Nuclear Engineering, Seoul National Univ., Seoul, 151-742, Korea

*Dept. of Applied Physics, Dankook Univ., Seoul, 140-714, Korea

Abstract

For the RF source of the LINAC in KOMAC (Korea Multi-purpose Accelerator Complex), 1 MW grade CW klystrons were proposed. But generally the efficiency of a klystron is about 60%. For the 1 MW CW klystrons, 1.6 MW CW power supplies are needed. About 31 klystrons are required in a total for KOMAC and about 18.6 MW CW power is dumped for useless. It is undesirable in economical aspect. So the feasibility study on energy recovery system by beam direct conversion in the klystron is proposed to utilize the wasted energies. Here the new concept of energy recovery system with Magnetic Energy Separator (MES) is proposed to break through the efficiency limit of conventional energy recovery systems. The simulation of the energy recovery system with MES was carried out and the basic results were presented. The comparisons between this system and conventional systems were also presented. The expected recovery efficiency was above 85%.

1 INTRODUCTION

For the RF source of the LINAC in KOMAC (Korea Multi-purpose Accelerator Complex), MW grade CW klystrons were proposed. The number of klystrons for CCDTL and SC Linac is about 31. [1] But generally the efficiency of klystron is about 60% - 65% for the 1 MW CW klystron. So a lot of power, about 18.6 MW, is dumped to spent beam collector for useless. (Fig.1 shows schematic diagram of energy flow in klystron.) Not only for energy waste in klystron but also the heat load on collector surface is important. In order to remove the heat from collector surface, additional power is required for cooling system. The cost and size of klystron power supply are also dependent on klystron efficiency. Therefore, klystron efficiency is very important factor in economical respect.

There are two ways to enhance the efficiency of klystron. One is to increase the klystron tube efficiency (or electronic efficiency) and the other is to recover the power from spent beam. To increase the klystron tube efficiency, continuing efforts are going on. But the designs of klystrons almost achieved theoretically maximum efficiency. [2] Therefore the spent beam energy recovery efficiency should be increased in order to increase the klystron efficiency furthermore.

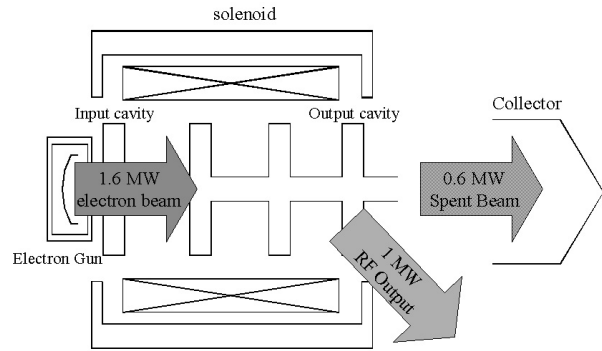


Figure 1: Schematic diagram of energy flow in klystron

2 DISADVANTAGES OF CONVENTIONAL ENERGY RECOVERY SYSTEM

There have been many researches about energy recovery systems of microwave tubes since 1953. [3][4] Especially klystron has low energy recovery efficiency compared to other microwave tubes because its RF output power is high and thus spread of energy distribution in spent beam is severe.

Conventional energy recovery systems use multi-stage depressed collector. [2][3][4] Figure 2 shows one of the conventional energy recovery systems in klystron. With this system the recent research showed that the recovery efficiency can be up to about 55% at saturation power in 1.2 MW L-band CW klystron. [2] However, in depressed collector, spent electron beams are decelerated and their axial velocities become zero and then they are accelerated back until they are collected on the surface of collector. Thus there should be increase of energy after fully decreased. This makes difficult to enhance the efficiency further more. To break through this difficulty, new concept of energy recovery system is proposed.

3 ENERGY RECOVERY SYSTEM WITH MAGNETIC ENERGY SEPARTOR (MES)

There is energy recovery system in neutral beam injection (NBI) system to heat plasmas in fusion device. In neutral beam injection systems, negative or positive ions are accelerated and converted to neutral atoms in neutralizer. The neutralization efficiency is below 60% for 300 keV negative deuteron beam and unneutralized ion beams are dumped for useless. So they need energy recovery system to increase efficiency of NBI system.

Unlike that of microwave tube, its efficiency reach over 90% because the spent beam energy is almost mono-energetic. [5][6]

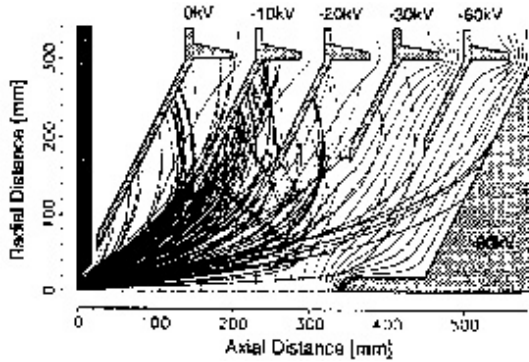


Figure 2: Conventional energy recovery system with depressed collector [2]

So we can increase the energy recovery efficiency of klystron significantly if the spent beam energies are locally mono-energetic in energy recovery zone. When magnetic field whose direction is perpendicular to electron beam axis is applied in the energy recovery region, the electron beam trajectories make semicircles and they are sorted in direction of perpendicular to both magnetic field and beam axis according to their energy. Thus we can collect the spent beam with little energy loss when we put collectors with right applied potential with right position.

4 SIMULATION RESULTS OF ENERGY RECOVERY SYSTEM WITH MES

Characteristics of CW model klystron for KOMAC is shown in table 1. That shown in table 1 is referred to EEV K3510 klystron because it has same specifications as that of model klystron for KOMAC.

Table 1: Characteristics of CW model klystron for KOMAC

Operating frequency	700 MHz
Output Power	1.0 MW
Gain at Saturation	41 dB
Beam Voltage	95 kV
Beam Current	16.2 A
Tube Efficiency at Saturation (without energy recovery)	65%

4.1 Input Data for Simulation

It is important to know the exact information of energy and current density distribution of spent beam in model klystron. But there is not such information available for model klystron shown in table 1. So the spent beam information for input data of simulation were assumed, which was referred to [2][3]. The input data

are shown figure 3. Figure 3(a) shows energy distribution of spent beam and figure 3(b) shows current distribution of spent beam along beam distance. Beam axis is assumed at $x=150$ mm and all input data is symmetry to the beam axis. Figure 3(c) and 3(d) shows energy and power distribution of spent beam, respectively, along beam distance.

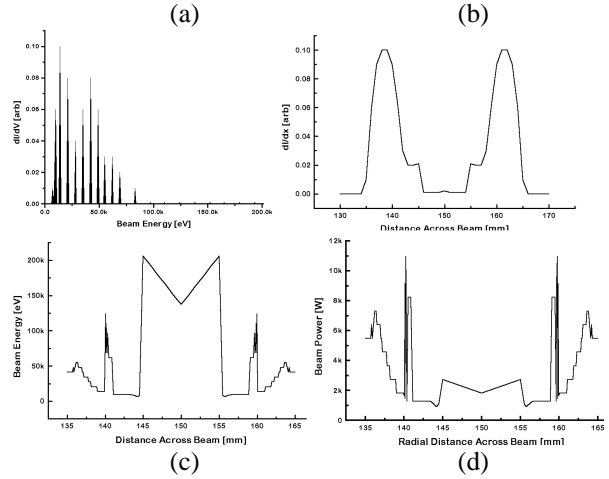


Figure 3:Input data for simulation; (a)Energy distribution of spent beam (b)current distribution of spent beam (c)energy distribution along beam distance (d)power distribution of spent beam

4.2 Simulations Results

The calculated trajectories of spent beam in energy recovery system with MES is shown figure 4. Initial spent beam direction is parallel to z axis and x axis is defined perpendicular to z axis shown in figure 4. Uniform magnetic field is applied with direction out of paper, so direction of y axis is defined, and exists only from $z=150$ mm to $z=600$ mm. In the magnetic field region, spent beam makes semicircle with radius according to its energy and separated along x axis after it exits magnetic field region. Spent beam collectors are located along x axis and appropriated potential is applied for the spent beams entering to collector region. Total 8 collectors are introduced for this simulation. Simulations are carried out with EGN2W code [7] with rectangular coordinate. Applied magnetic field was 40 Gauss.

On the other hand, spent beams are freely spread out in direction with parallel to magnetic field, that is y axis in this simulation. Simulation result of free spread out with cylindrical coordinate are shown in figure 5. The results shows that spread range for major spent beams and entire spent beams are about ± 200 mm and ± 350 mm, respectively, when they drift 1,350 mm. It is possible to make uniform magnetic field region of 40 Gauss with volume about 600 X 750 X 700 mm.

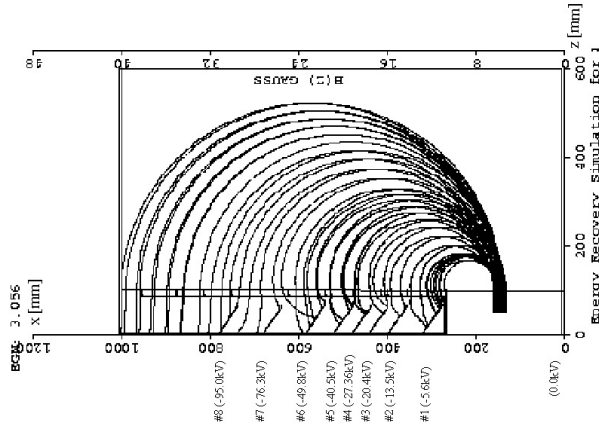


Figure 4: Calculated trajectories in recovery system with MES

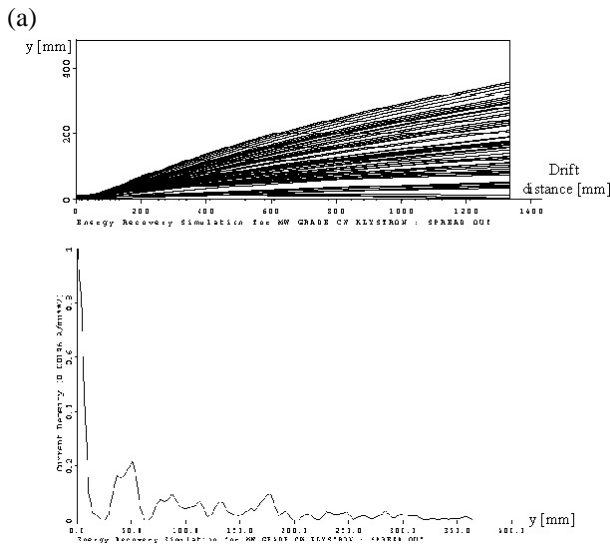


Figure 5: Free spread out of spent beam; (a) spent beam trajectories (b) current distribution along y axis

Simulation results related recovered and loss power are shown in table 2. The recovery efficiency with MES reaches to 70.6% and consequently total efficiency of model klystron reaches up to 89.7%. Comparisons between this system and conventional recovery system are shown in table 3.

5 CONCLUSION

New concept for energy recovery system with MES in klystron is proposed and simple simulations have been performed. The results of simulation showed that significant enhancement of efficiencies both in the recovery system and in the total klystron system are obtained and its values are 70.6% and 89.7%, respectively.

Table 2: Simulation results of recovery system with MES

Number of Electrode	Applied Potential (kV)	Recovered Power (kW)	Loss Power (kW)	Spent Beam Power
1	-6.6	28.8	24.2	
2	-13.5	27.7	14.9	
3	-20.4	36.6	18.5	
4	-27.3	49.0	19.9	
5	-40.5	119.5	19.1	
6	-49.8	89.5	28.3	
7	-76.3	9.8	1.2	
8	-95.0	19.3	28.8	
Body loss	0.0	0.0	3.8	
Total Power		380.2	158.7	538.9kW
Percentage		70.6%	29.4%	100.0%

Table 3: Comparison of simulation results with conventional energy recovery system

	Recovery system with MES	Conventional Recovery System
Recovery Efficiency	70.6%	35%-55%
Tube Efficiency	65% @ Saturation	50%-65% @ RF full power
Total Efficiency	89.7% for model klystron	Below 70%
Number of collector	8	1 - 10
Secondary Electron consideration	Not considered (difference<1%)	considered

6 REFERENCES

- [1] J.H. Lee, et. al., APAC98 Conference Proceeding, to be published
- [2] K. Masuda, et. al., Fusion Technology, Vol. 30, 805 (1992)
- [3] W. Neugebauer, et. Al., IEEE Transactions on Electron Devices, Vol. ED-19, 111 (1972)
- [4] H. G. Kosmahl, Proceedings of IEEE, Vol. 70, No.11, 1325 (1982)
- [5] R. W. Moir, Fusion Technology, Vol. 25, 129 (1994)
- [6] K. Yoshikawa, et. al., Fusion Technology, Vol. 17, 527 (1990)
- [7] W. B. Herrmannsfeldt, "EGUN-An Electron Optics and Gun Design Program", SLAC-Report-331 (1988)